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CHANGES IN MOSQUITO POPULATIONS WITH EXPANSION OF THE ROSS RIVER RESERVOIR, AUSTRALIA, FROM STAGE 1 TO STAGE 2A

MARK N. HEARNDEN AND BRIAN H. KAY

Queensland Institute of Medical Research, PO Royal Brisbane Hospital, Brisbane Q 4029 Australia

ABSTRACT. Female mosquitoes were collected at 4 sites around the Ross River reservoir (Stage 2A) from 484 carbon dioxide-supplemented light traps. The seasonal abundance from these collections during 1991–93 was compared statistically with that for similar collections done for the Stage 1 reservoir in 1984–85. Principally due to clearing of the forest prior to the inundation of the Stage 2A, several tree hole/plant axil and shaded pool species are no longer present or are rare. Due to extensive loss of marginal emergent vegetation and creation of expanses of shallow muddy pools, mean number per trap of *Anopheles amictus* and *Aedes normanensis* increased up to 36- and 282-fold, respectively, from Stage 1 to 2A. For *Culex annulirostris*, mean abundance did not exceed densities recorded for Stage 1. However, from examination of trends from 1991 to 1993, mean catches of *Culex*, *Anopheles* spp., and *Mansonia uniformis* were increasing despite the progressive reduction of the inundated area of the reservoir. Cluster analysis of species abundance indicated broad similarities with Stage 1 data, and differences in faunal composition of the reservoir area compared with that around Townsville. In view of the continuing stabilization of the Stage 2A reservoir area, continued surveillance of major vector species is recommended.

INTRODUCTION

Habitat changes that occur after the construction of water resource projects may result in increased abundance of medically important insect vectors. In tropical regions, such projects have been associated with increased social, health, and nutritional problems for the surrounding population (Sornmani and Harinasuta 1988, Birley 1989).

The Ross River dam (19°26'S, 146°45'E) is a freshwater reservoir situated immediately south of Townsville in north Queensland and although currently closed to recreational users, it is unique in that it is the only major reservoir adjacent to a significant population center in tropical Australia. Since 1973, it has undergone 2 major stages of construction. The initial stage was completed in 1974 and mosquito surveillance was conducted from January 1984 to September 1985. Human bait and EVS light traps were compared as surveillance tools and both found satisfactory (Jones et al. 1991). Although mosquito abundance at the reservoir was significantly increased relative to surrounding locations, arbovirus conversion rates in sentinel chicken flocks did not indicate that there was any increased risk of infection by alpha- or flaviviruses even though mosquito and arbovirus activity in the area was high (Kay et al. 1990, Barker-Hudson et al. 1986, 1993).

Since 1987, the capacity of the reservoir has been doubled and the inundated area has almost tripled at full supply level. Due to the topography of the reservoir basin, a significant proportion of the increased areas covers shallow grasslands, cleared of previously existing open forest. This may lead to a far greater increase in mosquito abundance than was the case with the initial development. It may also lead to changes in the dominant species present as relative proportions of the important breeding habitats change. With continued urban development and the likelihood of the lake being opened for recreation, this present study examines the changes that may have occurred in the mosquito population as a basis for assessing risk.

METHODS

Study area: The Ross River reservoir was constructed in 1973 with a storage capacity of 72×10^9 liters at full supply level. In 1974, the spillway was heightened to give the reservoir an increased capacity of 109×10^9 liters, which covered approximately 3,000 ha. This was designated Stage 1 of construction. In 1987 the spillway was further augmented to establish the reservoir's present capacity of 236×10^9 liters, covering 8,090 ha at full supply level and more than 14,000 ha at maximum flood discharge. This level was designated at Stage 2A. Further details of the reservoir are given in Kay et al. (1990) and Barker-Hudson et al. (1993).

Mosquito surveillance: Adult mosquitoes were collected by CO_2-supplemented EVS traps (Rohe and Fall 1979) from February 1991, 2 years after the initial inundation of Stage 2A of the reservoir, to June 1993. Traps were modified with a photoresistor that started the trap fan and light at dusk and switched them off at dawn. The design also employed a self-closing baffle that prevented the escape of trapped mosquitoes from the collection bag after the motor was switched off. Traps were suspended 0.5–1 m above ground level and the methods used followed that for the Stage 1 study from January 1984 to September 1985 (Barker-Hudson et al. 1993). Traps were set between 1 and 2 h before sunset and the catch collected up to 1 h after sunrise. Collected mosquitoes were sorted, identified to species, and counted.

Data on adult mosquitoes collected over 29 months of the Stage 2A trapping period were also compared with Stage 1 data. However, for the Stage comparison, only data from comparable time periods were analyzed (i.e., January 1984–September 1985 with February 1991–October 1992).

Traps for the Stage 2A study were situated at 4 localities around the reservoir margin. Each location was trapped approximately monthly (some months were missed) with a total of at least 6 traps, either 6 traps set on one evening or 3 traps set on 2 consecutive nights. Trap sites at each location were approximately 400 m apart. Trap locations were situated to represent 2 distinct zones:

1. Zone 1 (2 trap locations). One location was situated along the northern shoreline (Big Bay), and the other on the southwestern shoreline (Ross River). Both locations were well vegetated with open eucalypt woodland. Paperbark ti-trees (*Melaleuca* spp.) were also present at Ross River. The water margins at both locations remained relatively close (100–200 m) to the trap sites during periods of lower water levels present through the late dry season.
2. Zone 2 (two trap locations). Both locations were situated along the eastern edge of the reservoir, Antill Creek on the northern end of the section, and Toonpan on the southern end. Both locations were extensively cleared of open eucalypt woodland before completion of Stage 2A and were essentially open grassland with patches of Chinee apple (*Zizyphus mauritania*). Although traps were situated adjacent to the shoreline during periods of flood (water levels >38.2 m spillway height), the margins receded rapidly after the cessation of rainfall and some were up to 2 km from standing water by the late dry season (October). Trapping did not commence at Toonpan until May 1991 due to flooding of the access road.

For analyses of comparative adult temporal abundance during Stage 1 and 2A, 2 locations common to both trapping studies, Big Bay in Zone 1 and Toonpan Creek in Zone 2, were used. Daily rainfall at the base of the spillway and spillway water-levels were recorded by the Townsville–Thuringowa Water Supply Board.

Statistical analysis: For formal analyses, all mosquito counts were transformed to $\log(n + 1)$ to stabilize the variance. All analyses were carried out using the SAS statistical package (SAS Institute 1988). Analysis was divided into 2 main sections. The first analyzed catch data from the Stage 2A study with ANOVA designs used by Barker-Hudson et al. (1993) and the second compared the temporal abundance of the 5 most dominant species caught at the 2 localities (Big Bay and Toonpan Creek) used for both 1 and 2A studies.

Analysis of Stage 2A populations: Cluster analyses were used to determine similarities in species composition for the 4 reservoir locations. Species were classified into 2 groups: those breeding in the reservoir, and those not recorded from larval sampling in the reservoir (Rae 1983[1]; Hearnden, unpublished data). Analyses were performed on mean catches of species in each group. Although reservoir-breeding species are expected to determine the extent of the influence that the reservoir has on regional mosquito faunas, non-reservoir-breeding species are expected to provide a form of "control" pattern. There is no reason to expect these non-reservoir-breeding species to follow zonal patterns that may be influenced by the reservoir (Barker-Hudson et al. 1993). All procedures used (average linkage, centroid, flexible beta and complete linkage) (SAS Institute 1988) provided the same clustering sequences. Average linkage clustering results are presented.

Seasonal patterns of abundance for individual species and the total catch for the Stage 2A study were performed using mixed-factor analysis of variance for unbalanced designs. The model examined the effect of zone and location within zone. The sampling period was arranged as 2-monthly intervals (to accommodate the data set to the computing capacity available) with individual trap-nights within each interval treated as replicates. Treatments were Zone and Month (fixed factors) and Locations (random factor) within Zone. Analysis of variance (ANOVA) was

[1] Rae, D. J. 1983. The mosquito larvae of Ross River Dam with particular reference to the ecology of *Culex annulirostris*. Unpublished B.Sc. (Honors) thesis. James Cook University of North Queensland, Townsville, Australia.

applied to total mosquitoes and 5 abundant species. Four of these, *Culex annulirostris* Skuse, *Anopheles annulipes* Walker *s.l.*, *Anopheles amictus* Edwards, and *Mansonia uniformis* (Theobald), are known to breed within the reservoir; whereas *Aedes normanensis* Taylor breeds in freshwater flood pools surrounding the reservoir.

Comparison of Stage 1 and 2A populations: To examine any changes that may have occurred with increased reservoir capacity, the seasonal patterns of abundance of the total catch and for species that were dominant during both stages were compared with fixed-factor analysis of variance. The species used in this comparison were 3 reservoir-breeding species, *Cx. annulirostris, An. annulipes,* and *Ma. uniformis.* The model used for this analysis examined the effect of Stage, Location, and Month. The variable Stage, as mentioned previously, represents the 2 study periods. Months, as with the mixed-factor ANOVA, has been divided into 2-month intervals.

RESULTS

Rainfall and water levels: Rainfall and its effect on reservoir water levels (in hectares covered) during both studies is shown in Fig. 1. Rainfall was typically seasonal in both studies, with maximum recordings each year occurring in the summer period (generally December–March). Patterns were very similar in each study period with highest summer rainfalls occurring in the first year followed by lower than average falls in the following year(s). The effect on water level was also comparable, with full capacity being reached in the initial wet season period (3,000 ha for Stage 1 and 8,000 ha for Stage 2A) and declined to approximately ⅓ of full capacity.

Analysis of species composition: For Stage 2A, a total of 50,430 females, comprising 22 species, were caught (Table 1). Of these, *An. amictus* (34.5% of the total catch), *Ae. normanensis* (28.9%), *An. annulipes* (18.3%), and *Cx. annulirostris* (12.3%) were the most abundant species, comprising 93.9% of the total. Mean numbers per trap were highest at Toonpan (191.0) and Antill Creek (116.5) in Zone 2 and were lower for Ross River (72.6) and Big Bay (72.4) in Zone 1. Total mosquitoes at each location within each zone did not differ significantly (ANOVA, $F_{1,439} = 0.06$, $P = 0.81$), but mean number per trap in Zone 2 (150.7) was significantly higher than Zone 1 (72.5) (ANOVA, $F_{1,439} = 16.61$, $P < 0.0001$).

The number of species was higher for the Zone 1 locations, with 20 and 16 taxa recorded at Ross River and Big Bay, respectively. For Zone 2, number of species at Toonpan and Antill Creek was 12 and 15, respectively. The numbers of species trapped were 5 and 10 fewer at Big Bay and Toonpan, respectively, from Stage 1. Four *Aedes* species (*Aedes mallochi* Taylor, *Aedes purpureus* (Theobald), *Aedes quasirubithorax* (Theobald), and *Aedes alboscutellatus* (Theobald)), *Culex quinquefasciatus* Say, and both *Uranotaenia* species were recorded during Stage 1 only.

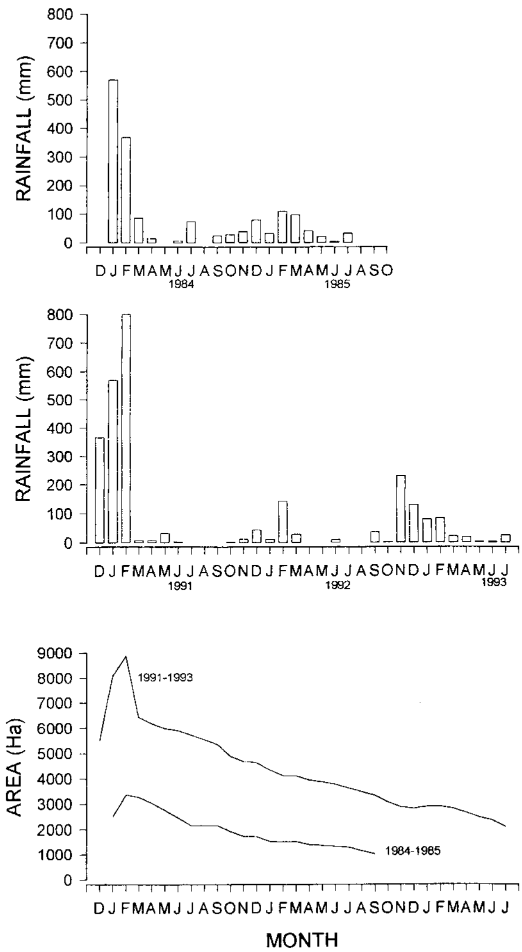


Fig. 1. Monthly rainfall totals (mm) recorded for the reservoir from January 1984 to September 1985 (top figure) and December 1990 to July 1993 (middle figure), and lake area in hectares for each period (bottom figure).

Cluster analysis of reservoir-breeding species (Fig. 2) separated the reservoir locations into 2 distinct groups. These groups comprised locations within each of the 2 zones. Separation of the 2 reservoir zones appears to have been on the basis of significantly lower numbers of *An. amictus* and higher numbers of *Cx. annulirostris* and to a lesser extent, *Ma. uniformis* and *Culex bitaeniorhynchus* Giles in Zone 1 locations.

Clustering on non-reservoir-breeding species

Table 1. Numbers of mosquitoes caught in carbon dioxide-baited EVS light traps from surveillance sites at the Ross River reservoir from February 1991 to June 1993 (Stage 2A) and from January 1984 to September 1985 (Stage 1). Species listed in bold were not trapped during Stage 2A.

	Zone 1			Zone 2		
Taxon	Ross River 1991–93	Big Bay 1991–93	Big Bay[1] 1984–85	Antill Creek 1991–93	Toonpan 1991–93	Toonpan[1] 1984–85
Aedes alboscutellatus	0	0	0	0	0	12
Aedes alternans	17	3	1	18	40	5
Aedes elchoensis	8	4	10	0	1	99
Aedes kochi	2	0	1	0	0	34
Aedes lineatopennis	49	9	2	223	318	1,045
Aedes mallochi	0	0	0	0	0	3
Aedes normanensis	4,775	1,187	27	3,732	4,870	1,139
Aedes notoscriptus	4	0	0	0	0	28
Aedes purpureus	0	0	1	0	0	77
Aedes quasirubithorax	0	0	0	0	0	5
Aedes vigilax	166	306	379	165	90	373
Aedes vittiger	0	0	12	29	17	385
Aedeomyia catasticta	57	45	11	7	3	101
Anopheles amictus	736	1,810	97	5,336	9,495	65
Anopheles annulipes	1,469	5,129	8,850	1,365	1,248	1,175
Anopheles bancroftii	7	1	146	0	0	18
Anopheles meraukensis	108	56	107	120	283	227
Coquillettidia crassipes	10	0	78	0	0	83
Culex annulirostris	1,738	2,425	2,478	1,280	774	4,885
Culex bitaeniorhynchus	91	292	29	64	0	20
Culex pullus	9	3	0	4	30	2
Culex quinquefasciatus	0	0	0	0	0	122
Culex squamosus	1	0	0	0	0	0
Mansonia septempunctata	3	1	330	0	0	74
Mansonia uniformis	334	31	2,188	8	24	72
Uranotaenia albescens	0	0	2	0	0	3
Uranotaenia nivipes	0	0	2	0	0	0
No. collected	9,584	11,302	14,751	12,351	17,193	10,052
No. of species collected	20	16	21	12	15	25
No. of collections	132	156	146	106	90	146

[1] Data from Barker-Hudson et al. (1993).

produced a significantly changed pattern with the only strong association between locations being for Antill Creek and Toonpan where higher numbers of *Ae. normanensis* and *Aedes lineatopennis* (Ludlow) were recorded during wet seasons. Any other pattern on the basis of zone was weak, with Big Bay as closely related to the Toonpan–Antill Creek group as it was to Ross River.

Analysis of seasonal and spatial variation in abundance for Stage 2A: Numbers of *Cx. annulirostris* per trap were higher at Zone 1 (14.5) than Zone 2 (10.5) (ANOVA, $F_{1,439} = 22.02$, $P < 0.0001$), but were similar at locations within each zone. Mean numbers within Zone 1 were 15.5 per trap at Big Bay and 13.2 at Ross River, compared with 12.1 at Antill Creek and 8.6 at Toonpan (ANOVA, $F_{1,439} = 0.18$, $P < 0.67$). Peak periods of abundance (Fig. 3) were strongly seasonal for all 3 years, occurring in the late-wet to post-wet season months (January–May) for both zones and locations within zones. Timing of these peaks differed between the 2 locations in Zone 1 (ANOVA, $F_{14,439} = 2.09$, $P = 0.03$) but corresponded at both Zone 2 locations. Populations established more slowly at the Ross River location, starting earlier in September to match densities at Big Bay by March–May.

Mean numbers of *An. annulipes* (Fig. 4) were highest at Big Bay (32.8 per trap) but mean numbers per trap were similar for Ross River (11.1), Antill Creek (12.8), and Toonpan (13.8) (ANOVA, $F_{1,439} = 5.10$, $P < 0.0001$). Seasonally, peak populations occurred from January to May, longer than the equivalent population increases for *Cx. annulirostris*. Population rises also occurred in the September–October period.

Anopheles amictus (Fig. 5) underwent the largest increase in numbers from Stage 1 to Stage 2A. It had the highest recorded mean for any species at Stage 2A (35.9 per trap), compared with significantly lower catches during Stage 1 (1.3 per trap). Densities recorded in Zone 2 (75.5 per trap) were significantly higher than for Zone 1 (8.8 per trap) (ANOVA, $F_{1,429} = 195.38$, $P < 0.0001$). Within Zone 2, means were higher at Toonpan (105.5 per trap) than at Antill Creek (50.3) and for Zone 1, Big Bay (11.6) was higher than Ross River (5.5). The timing of peak abundance varied between zones (ANOVA, $F_{14,439} = 5.89$, $P < 0.0001$) however, monthly abundance at locations within zones was similar (ANOVA, $F_{14,439} = 1.53$, $P < 0.09$). Populations increased in the late-wet season, March–May period, at Zone 2 locations (especially during 1992) with increases also occurring in spring periods (September–October). This was also apparent to a lesser extent at Zone 1 locations.

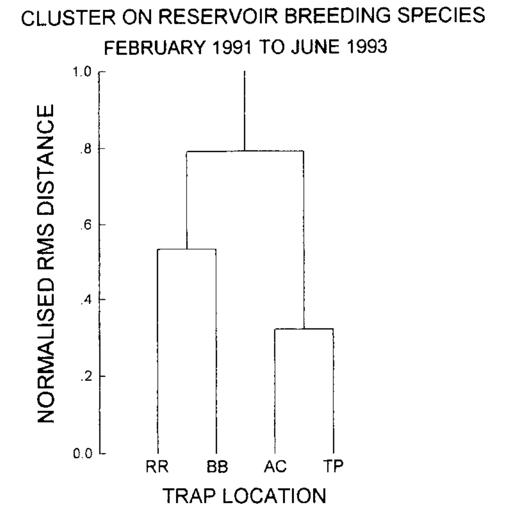
Aedes normanensis (Fig. 6) was the second most abundant species recorded at Stage 2A and was recorded in higher numbers than for Stage 1 (Table 1). Mean abundance was higher in Zone 2 (43.9 per trap compared with 20.7 per trap in Zone 1) (ANOVA, $F_{1,439} = 11.44$, $P < 0.0008$). Mean numbers were significantly different between locations within each zone. Highest numbers per trap occurred at Toonpan (54.0), whereas significantly lower numbers occurred at Big Bay (7.6) (ANOVA, $F_{1,439} = 44.59$, $P < 0.0001$). Peak abundance occurred during the wet season from November to March in all years; however, abundances were greater in 1993 at both Zone 2 locations (ANOVA, $F_{14,439} = 7.43$, $P < 0.0001$).

Mean abundances of *Ma. uniformis* (Table 1 and Fig. 7) were highest at Ross River (2.5/trap) and negligible at all other locations. Peak activity periods were generally during the late-wet season (March–May).

Comparison of seasonal and spatial abundance for Stages 1 and 2A: For Big Bay and Toonpan, *Cx. annulirostris*, *An. annulipes*, and *Ma. uniformis* were compared to examine changes in abundance between Stage 1 and Stage 2A (Table 2). *Culex annulirostris* was the only species where mean abundance at each location had not changed significantly (Stage by Location effect, Table 2). However significant Stage by Location by Month effects for each species was caused by year-to-year variation in relative abundance. For example, during Stage 1, numbers of *Cx. annulirostris* at Big Bay (Fig. 3) were highest in 1984 and decreased in 1985, compared with Stage 2 where abundance increased from 1991 to 1992. A similar pattern also occurred for *An. annulipes* at Toonpan (Fig. 4).

The abundance of *An. amictus* and *Ae. normanensis* increased the most between the 2 stages. *Anopheles amictus* increased from 0.6 to 11.6 per trap at Big Bay and from 0.4 to 105.5 per trap at Toonpan and *Ae. normanensis* increased from 0.2 to 7.6 per trap at Big Bay and from 7.8 to 54.1 per trap at Toonpan (Table 1).

Means for pooled January–June catches in each



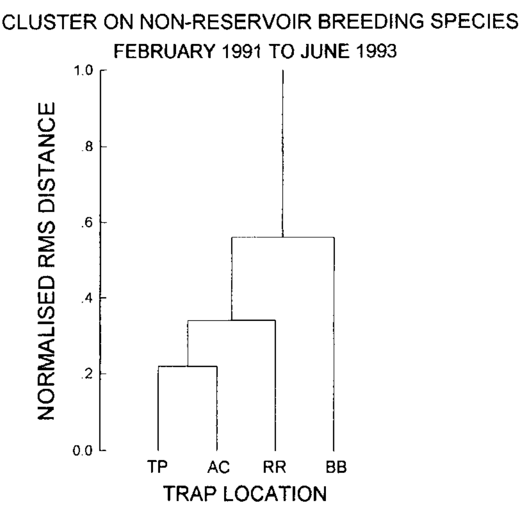
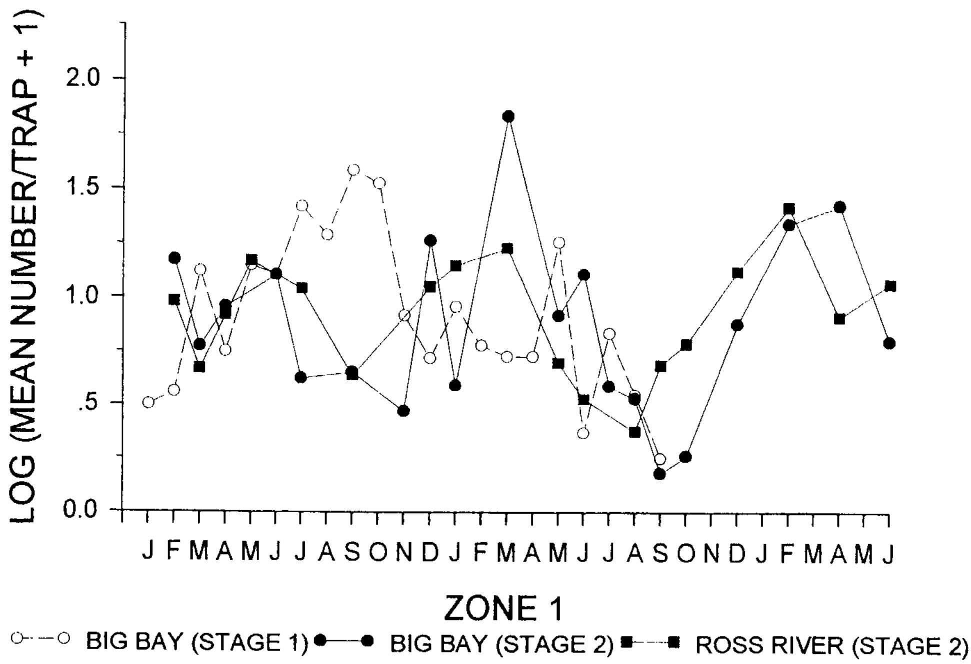


Fig. 2. Cluster analysis for reservoir-breeding species (top) and non-reservoir-breeding species (bottom) in relation to the locations trapped during the Stage 2A study.



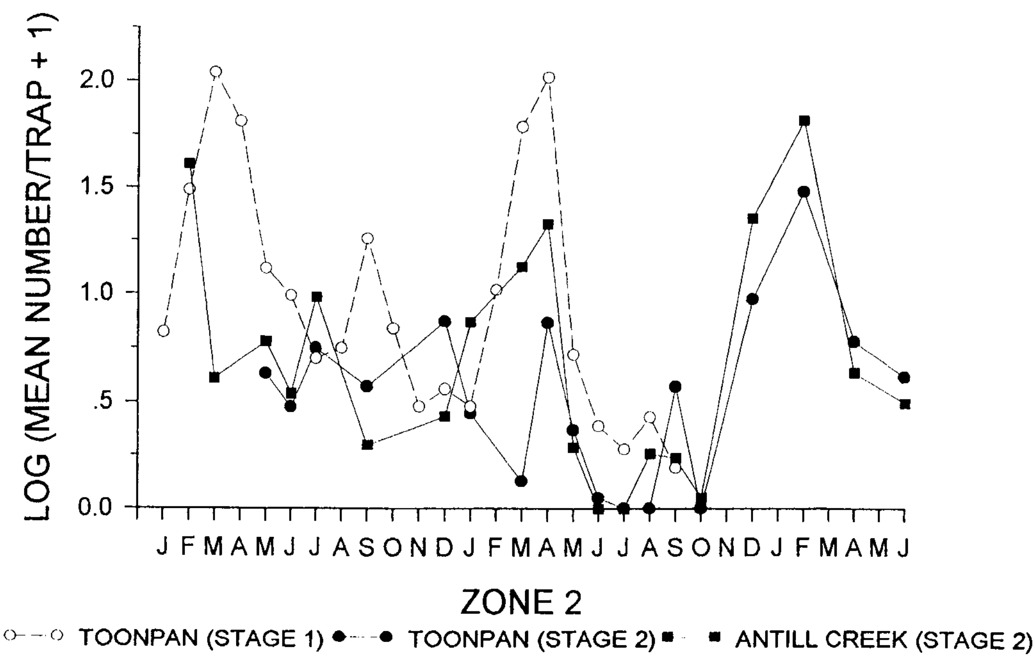
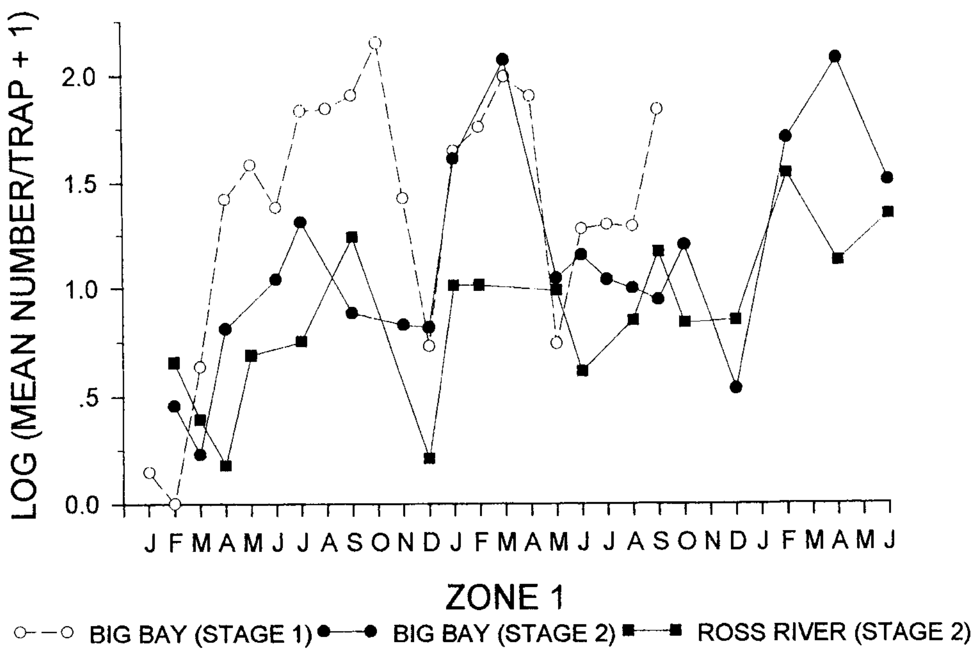


Fig. 3. Monthly trap means for *Culex annulirostris* for locations in Zone 1 (top) and Zone 2 (bottom) during Stage 2A. Dashed lines are comparative data for Big Bay (Zone 1) and Toonpan Creek (Zone 2) from Stage 1.



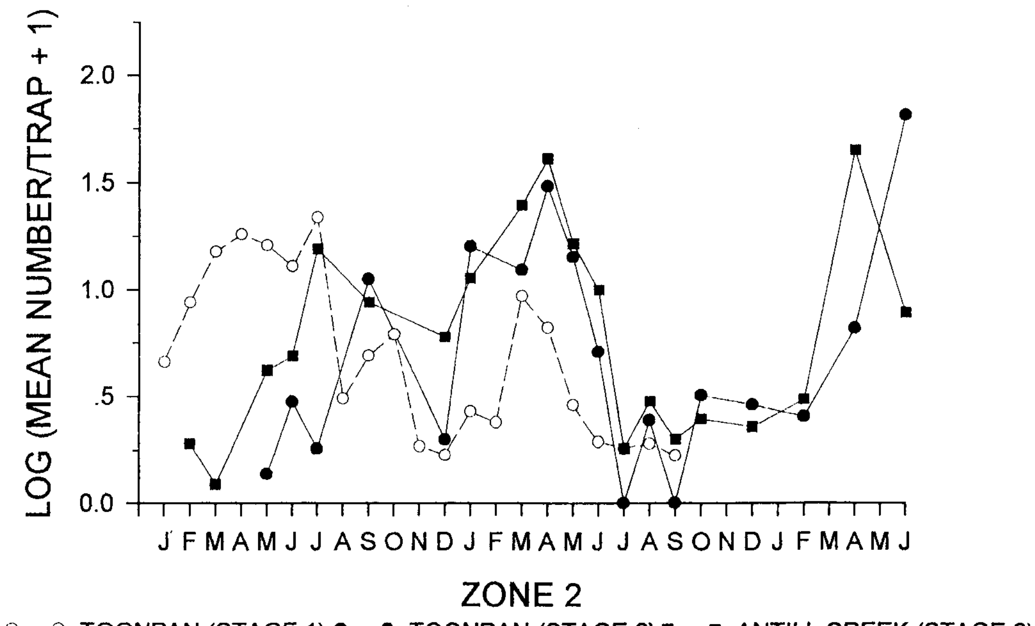


Fig. 4. Monthly trap means for *Anopheles annulipes* for locations in Zone 1 (top) and Zone 2 (bottom) during Stage 2A. Dashed lines are comparative data for Big Bay (Zone 1) and Toonpan Creek (Zone 2) from Stage 1.

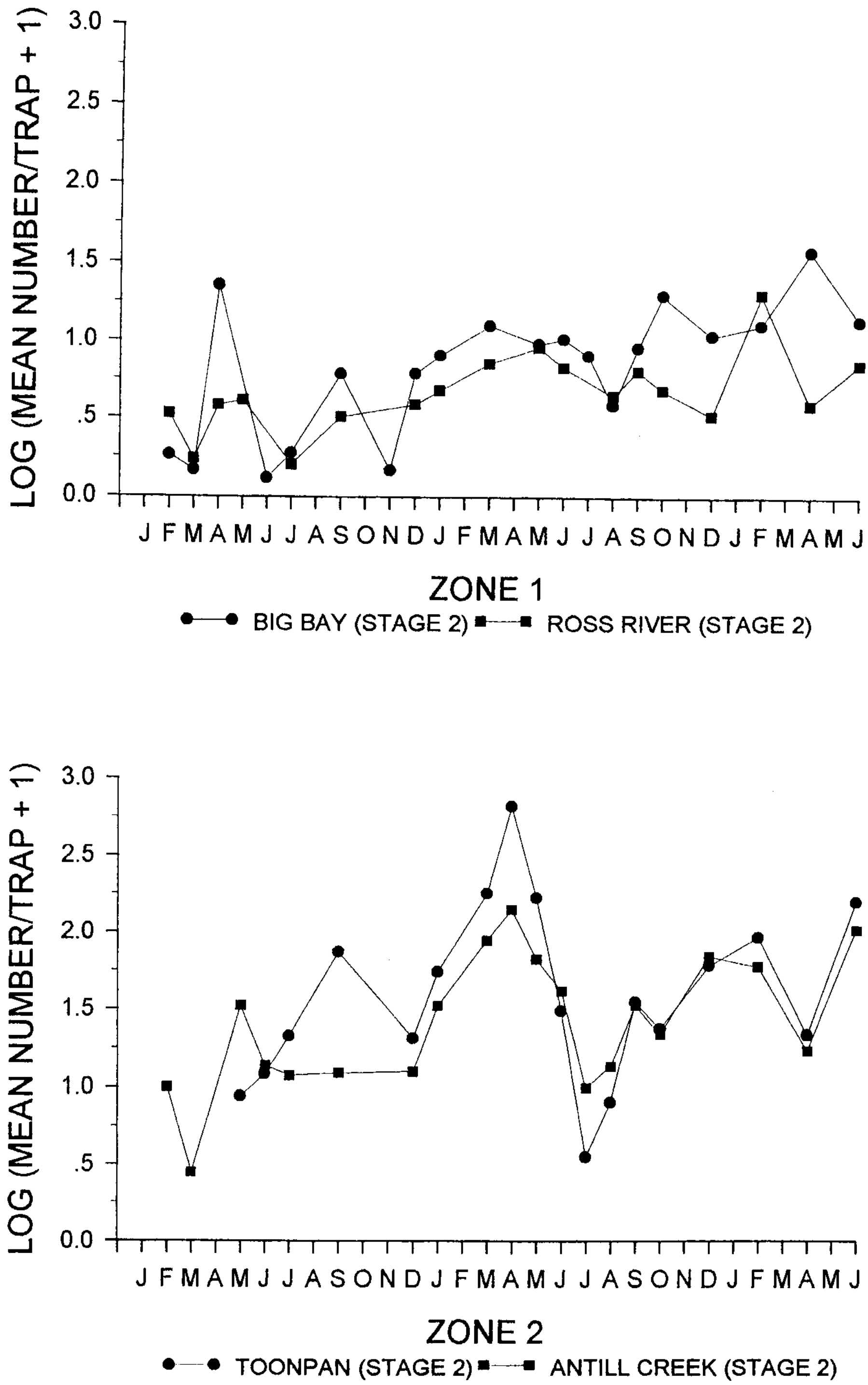


Fig. 5. Monthly trap means for *Anopheles amictus* for locations in Zone 1 (top) and Zone 2 (bottom) during Stage 2A.

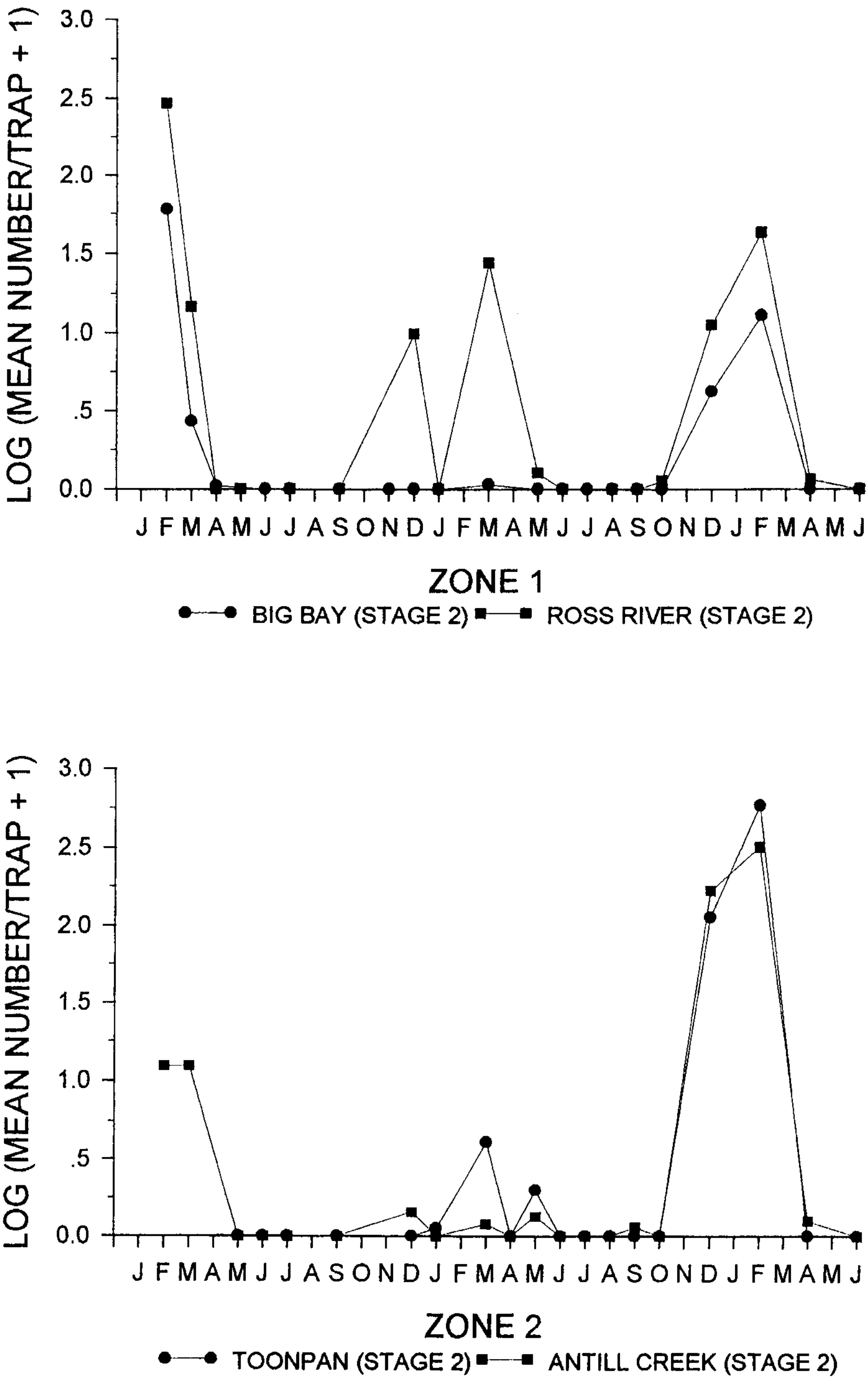
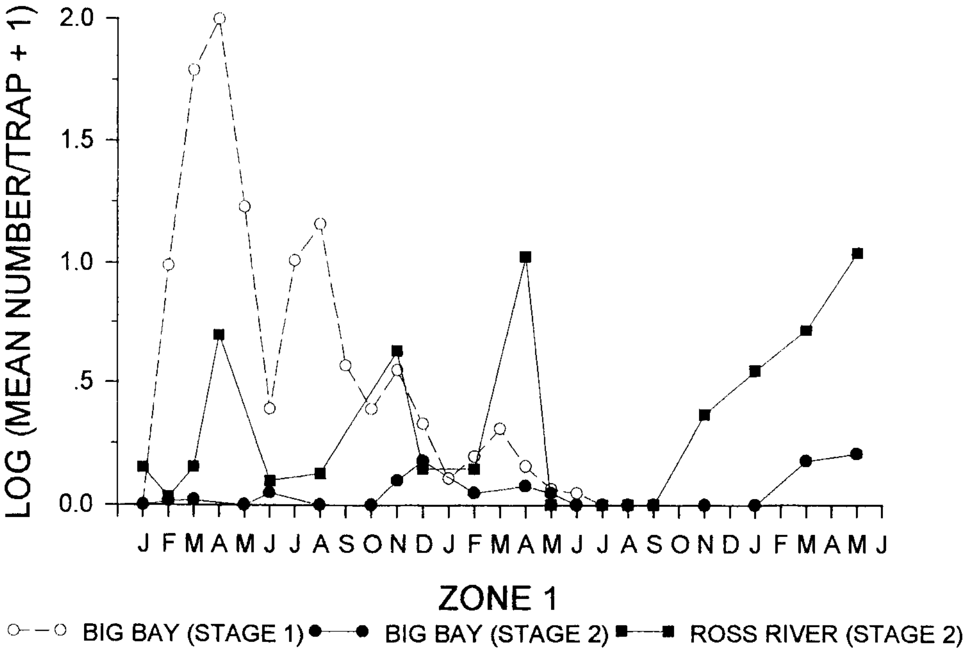


Fig. 6. Monthly trap means for *Aedes normanensis* for locations in Zone 1 (top) and Zone 2 (bottom) during Stage 2A.



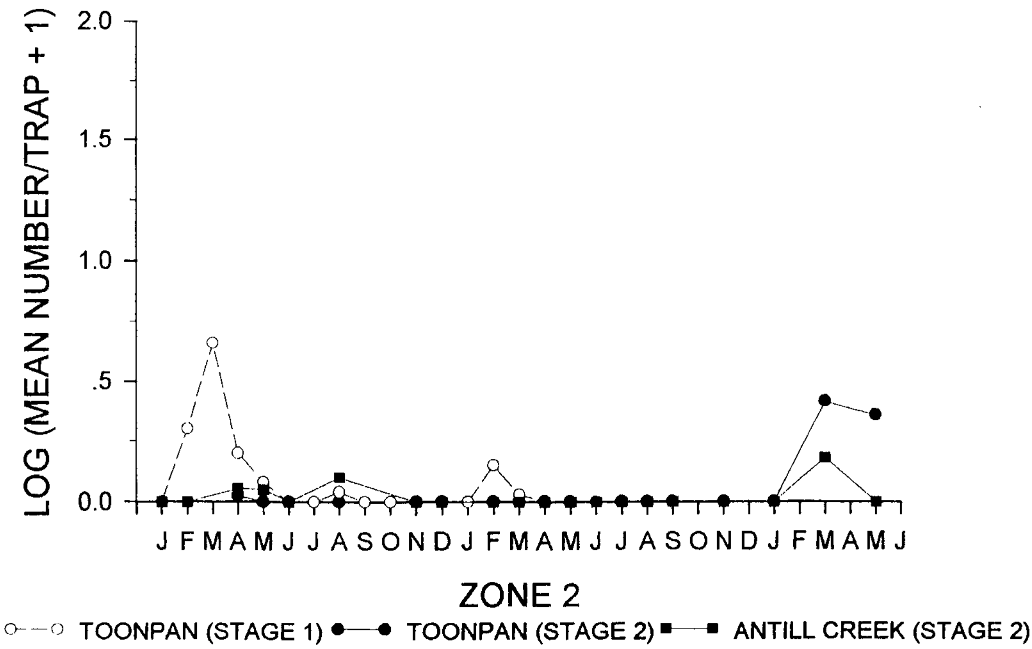


Fig. 7. Monthly trap means for *Mansonia uniformis* for locations in Zone 1 (top) and Zone 2 (bottom) during Stage 2A. Dashed lines are comparative data for Big Bay (Zone 1) and Toonpan Creek (Zone 2) from Stage 1.

Table 2. Fixed-model ANOVA results for comparisons of species abundance at Big Bay and Toonpan during Stage 1 and Stage 2A trapping periods. Tests were applied to log-transformed abundance data for each species.

Species	Effect	DF	F	*P*
Culex annulirostris	Stage	1	8.18	0.0044
(n = 4,903)	Location	1	4.96	0.0264
	Month	10	33.72	0.0001
	Stage × Location	1	3.22	0.0735 (NS)
	Stage × Month	10	3.80	0.0001
	Location × Month	10	7.84	0.0001
	Location × Stage × Month	8	7.51	0.0001
Anopheles annulipes	Stage	1	10.10	0.0016
(= 13,979)	Location	1	202.63	0.0001
	Month	10	19.34	0.0001
	Stage × Location	1	24.54	0.0001
	Stage × Month	10	8.73	0.0001
	Location × Month	10	15.14	0.0001
	Location × Stage × Month	8	5.19	0.0001
Mansonia uniformis	Stage	1	99.01	0.0001
(n = 2,219)	Location	1	86.34	0.0001
	Month	10	25.37	0.0001
	Stage × Location	1	67.06	0.0001
	Stage × Month	10	30.50	0.0001
	Location × Month	10	12.25	0.0001
	Location × Stage × Month	8	12.42	0.0001
All tests	Residual	455		
	Total	496		

year of both studies clearly show that abundance of each of the reservoir-breeding species increased from 1991 to 1993 at all locations (Fig. 8). Mean abundance of *Cx. annulirostris* at Toonpan, *An. annulipes* at Big Bay, and *Ma. uniformis* at both Big Bay and Toonpan did not exceed levels recorded in 1985. Abundance of *Ma. uniformis* has increased substantially at Ross River; however, the rise was less marked at each of the other locations. *Aedes normanensis*, despite being trapped at significantly higher numbers than during Stage 1, did not show the same general trend. Toonpan was the only location where abundance had risen consistently from the mean abundance recorded during Stage 1.

DISCUSSION

The artificial modification of reservoirs often leads to reduced heterogeneity of the habitat, including many aquatic microhabitats, which in turn decreases biodiversity (Harrison 1966, De Moor 1992). The expansion from Stage 1 to Stage 2A of the Ross River reservoir involved clearing of marginal scrub, grassland, and forest and the inundation of temporary wetland. Temporarily inundated grassland, *Melaleuca* spp., lilies (*Nymphoides indica* and *Nymphaea gigantea*), and submerged plants described by Rae (1983[1]) have been either inundated or transformed into a zone predominantly of shallow, unvegetated, muddy pools. This biotype became the principal producer of mosquito larvae within Zone 2, particularly after the flood-level wet season rains of 1990–91 began to recede and vegetation in this zone became restricted to sparse patches of filamentous algae (*Spirogyra* sp.). Although the drying out of large water bodies is known to favor breeding of *An. amictus* (Lee et al. 1987), populations of other dam-breeding species, particularly *Cx. annulirostris*, were reduced.

After comparison of collections from the Stage 1 (Barker-Hudson et al. 1993) and Stage 2A, the mean number of species in Zones 1 and 2 has declined from 19.7 to 18 and from 24 to 14, respectively (derived from Table 1). The species most affected included *Ae. alboscutellatus*, *Ae. mallochi*, *Ae. purpureus*, and *Ae. quasirubithorax*, which utilized tree holes and plant axils; those colonizing shaded pools (e.g., *Uranotaenia nivipes* (Theobald)); or those relying on attachment to arenchymous and lacunate macrophytes (e.g., *Mansonia* spp. and *Coquillettidia crassipes* (Van der Wulp)). The complete reduction of *Cx. quinquefasciatus* is probably a function of its limited flight range (Yasuno et al. 1973) and the trans-

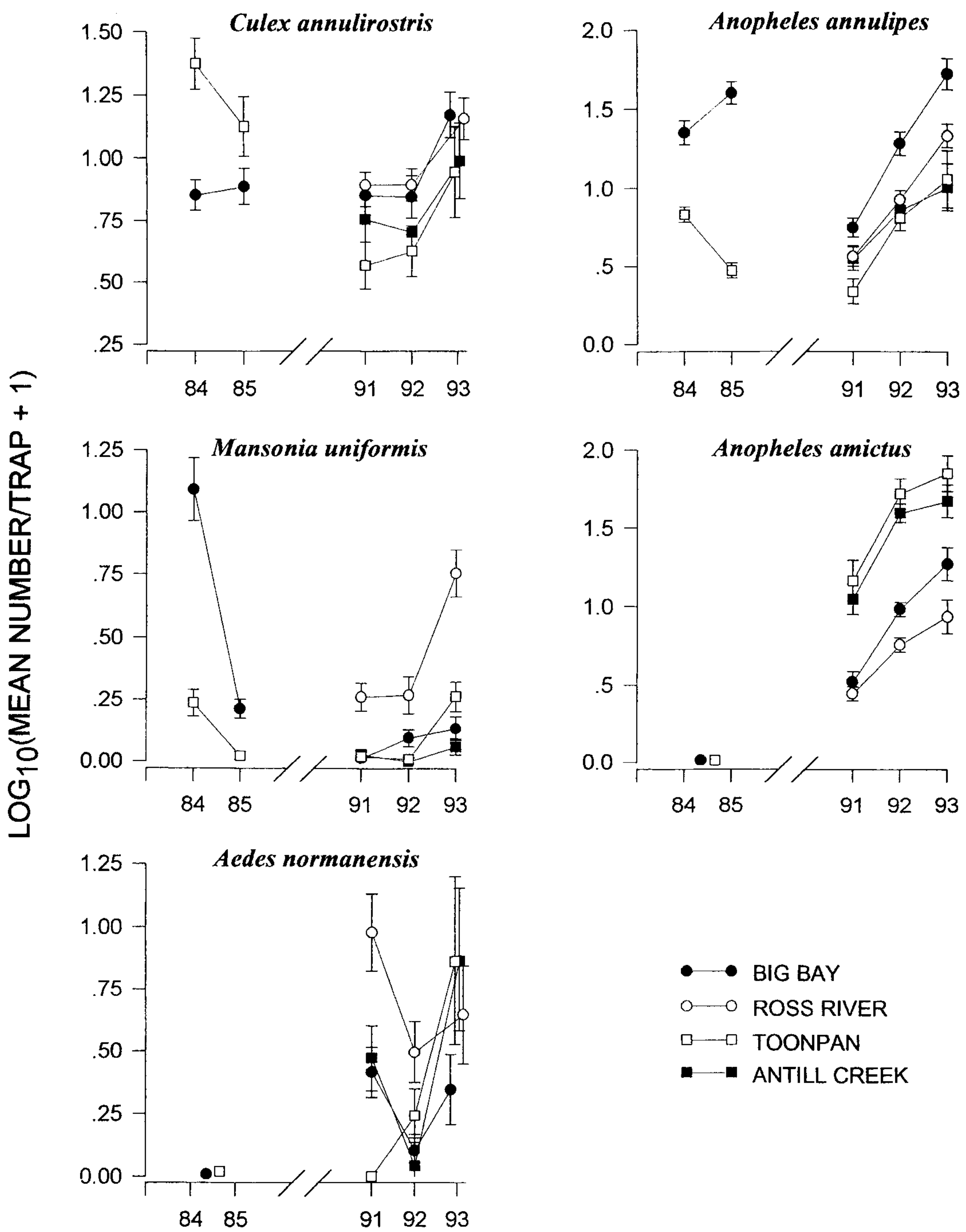


Fig. 8. Trap means ± SE at each trapping location for *Culex annulirostris, Anopheles annulipes, Anopheles amictus, Mansonia uniformis,* and *Aedes normanensis* for the January–June period of each year of the Stage 1 and Stage 2A studies. (For *An. amictus* and *Ae. normanensis,* the data shown for Stage 1 are the overall means for total catch at each location.)

location of settlements from Toonpan that were present during the Stage 1 study.

The cluster analysis of reservoir-breeding species (*Cx. annulirostris, Anopheles* spp., and *Mansonia* spp.) for the Stage 2A study demonstrated clear similarity between locations within each zone and the difference between zones. The cluster pattern for the Stage 1 study (Barker-Hudson et al. 1993) also clearly separated locations on the basis of zone. Although there has been a redistribution of the type and amount of habitat available, the zones have remained sufficiently distinct to support disparate mosquito faunas. Locations within Zone 1, Big Bay and Ross River, were characterized by larger surface areas of aquatic vegetation, predominantly *Hydrilla verticillata* and water lilies, compared with the relatively sparse and algal-dominated vegetation situated adjacent to the Zone 2 locations of Antill Creek and Toonpan. Similar to Stage 1, these locations also included expansive areas of clay-based soils suitable for oviposition by *Ae. lineatopennis* and *Aedes vittiger* (Skuse) after rainfall.

The timing of peak abundances of the common reservoir-breeding species, *Cx. annulirostris* and *An. annulipes* (Figs. 3 and 4) have not changed substantially between Stage 1 and Stage 2A, despite changes that have occurred in the relative year-to-year means. Numbers of *Cx. annulirostris* continued to show a maximum during the wet to early dry season period (January–May) and *An. annulipes,* from the end of the wet to the late dry season period (March–September).

Populations of reservoir-breeding mosquitoes increased from the initial inundation of Stage 2A through to the end of 1993 except for *Ae. normanensis* at Ross River (Fig. 8). This indicates that the quality of the breeding habitats was improving after the disruption of breeding habitats that occurred when Stage 2A was filled in 1989. Although it was noted that the efficacy of the light traps may be greater in cleared areas associated with Stage 2A, the trend has occurred during progressive reduction of the inundated area (Fig. 1). No such increase was apparent from 1984–85 Stage 1 studies.

Habitat clearing occurred prior to filling of Stage 2A. Clearing was carried out initially to avoid water quality problems from decaying vegetation and to reduce potential submerged and floating navigational hazards to recreational users of the reservoir. However, it also reduced or completely removed breeding sites for the group of *Aedes* species that utilize tree holes and plant axils. Inundation of established larval habitats also had the same effect by eliminating emergent and marginal vegetation. Increasing populations of reservoir-breeding mosquito species, to some extent, is concomitant with recolonization of vegetation in these new habitats. Inundation also transformed previously diverse habitat types, particularly in Zone 2, into areas predominated by shallow, muddy pools that supported larger numbers of fewer species.

Further to the conclusions drawn by Barker-Hudson et al. (1993), the results of the Stage 2A study support setting up a minimal surveillance program for mosquito numbers. The present analysis suggests that light-trap, or alternate surveillance (see Jones et al. 1991), at one location within each of the 2 zones should be ongoing in view of the trend toward increased *Cx. annulirostris* and *Anopheles* populations. The relationship between mosquitoes, arboviruses, and the size of these habitats will only be evidence once equilibrium has been reached.

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